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Stress Class Systems

An Idea Whose Time Has Come?

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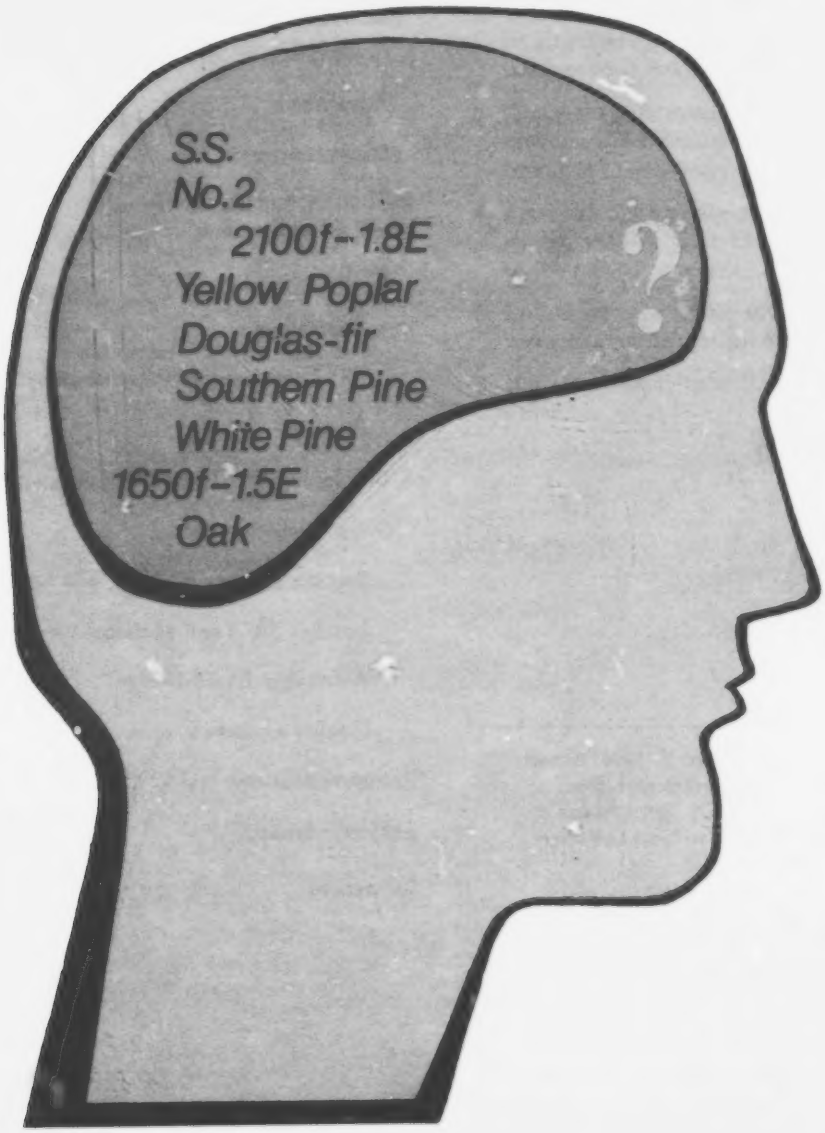

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Abstract

Stress class systems are species-independent grade classification systems for structural lumber. They are used throughout the world to reduce the number of species and grade choices that face the designer of engineered wood products. Stress class systems offer an opportunity to simplify lumber specification in the United States and to encourage more uniform quality standardization across product types. This report describes the major stress class systems used in Europe and the Pacific Rim countries and discusses the advantages and disadvantages of these systems. In addition, an alternative stress class system for use in the United States is proposed. It is recommended that development of a U.S. stress class system should be a consensus effort, involving the lumber industry, industry user groups, and design engineers.

Keywords: Stress class, lumber, grading, strength, stiffness, engineering standards

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Research Highlights

Stress class systems are species-independent grade classification systems for structural lumber. They are used throughout the world to reduce the number of species and grade choices that face the designer of engineered wood products and to standardize property assignment procedures between countries. A stress class system in the United States would offer an opportunity to simplify lumber specification and to encourage more uniform quality standardization across product types. Stress class systems used in Australia and the United Kingdom and those proposed in drafts of Eurocode 5 and International Standards Organization (ISO) standards are described. Using data from the U.S. and Canadian In-Grade Testing Program and published data for machine stress rated and composite lumber, this report discusses some of the advantages and disadvantages of stress class systems. Experience with stress class systems indicates that they offer the following advantages:

Grading-system independent

Species independent

Product independent

Permanent

Performance oriented

Simple

Nonrevolutionary to existing grading systems

Familiar

Reliable

Experience also indicates the following disadvantages with stress class systems:

Inefficient for some properties

Not totally species independent

No universally accepted stress class system

A new stress class system is proposed in this report. A complementary density class system is also suggested for use in fastener design and for properties that do not vary by grade.

On the basis of the information presented, the following recommendations are made:

1. Develop a stress class system for use in the United States.
2. Base modulus of rupture and modulus of elasticity provisions of the system on generally accepted international systems.
3. Apply the system to visually and mechanically graded solid-sawn lumber and to composite lumber products.
4. Establish appropriate provisions in the system for quality control procedures based on direct evaluation of the primary property.
5. Locate an appropriate consensus forum for development and implementation of a stress class system.
6. Base final assignment of grades to stress classes on reliability analysis.

Stress Class Systems

An Idea Whose Time Has Come?

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Introduction

Pity the U.S. engineer who, for the first time, must select a lumber product to meet structural design requirements. The National Design Specification (NDS) (NFPA 1988) lists about 56 species or species combinations of visually stress rated (VSR) lumber on 20 pages of tables. For visually graded dimension lumber (nominal 2- by 4-in. (actual 38- by 89-mm)), 787 combinations of grade and size are available for each of six allowable properties at 19 percent moisture content (MC). Add the 28 combinations of machine stress rated (MSR) lumber listed in the NDS and several combinations of composite lumber products available elsewhere, and no wonder the engineer often forgets about selecting lumber for the design.

Design engineers in other countries have similar problems. Some countries have developed an alternative approach that greatly simplifies the proliferation of choices faced by the engineer. In the Philippines, for example, more than 3,000 timber species are available, with several hundred being merchantable as structural lumber (Espiloy 1977, 1984). Such a large variety of species presents enormous problems in efficient utilization. In contrast, European engineers must reconcile differences in property assignment and grading procedures among those of many countries. A solution to these problems is a stress class system.

A stress class system is not a grading system. Rather, it is a grade classification system that presents an ordered set of design parameters. Consider the set of pigeonholes in Figure 1, each of which has been assigned a set of properties. Each pigeonhole is a stress class, and the set of pigeonholes constitutes a stress class system. Any lumber type can be classified using a stress class system, whether it is hardwood or softwood, visually or mechanically graded, solid or composite. The only requirement is that the lumber have the properties specified for the applicable stress class.

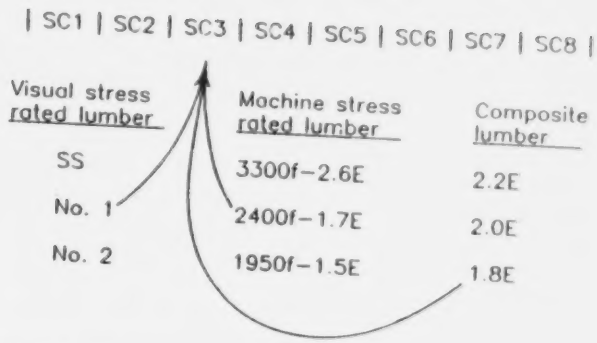

Figure 1—Representation of assigning various products into an idealized stress class system.

The objective of this report is to evaluate several stress class systems that might be useful for simplifying specifications of engineered wood members in the United States. We discuss the development of stress class systems, describe several stress class systems in detail, examine the decisions that must be made in setting up a stress class system, and present recommendations for a stress class system for use in the United States. Our recommendations are limited to dimension lumber but could be extended to thicker lumber.

Background

Stress class systems are developed by assigning class boundaries for primary properties, usually modulus of rupture (MOR) and modulus of elasticity (MOE), with secondary properties assigned concomitantly. Thus, maximum efficiency is usually obtained in assigning the primary properties, with less efficiency in the assignment of the secondary properties. Historically, two methods have been used to establish stress class boundaries for the primary properties. The first method involves ranking the strength values for the grades of important species groups. Class boundaries are then established that make the most efficient use of natural breaks in the ranked properties. The second method

uses a mathematical series to choose the class boundaries. In both methods, the species that fall into the various classes are determined. In the second method, values for the stresses can be established by arithmetic or geometric series, where each stress class level is a step in the series. The series usually recommended for establishing stress class boundaries is the preferred number series (Pearson 1965, Booth 1967).

Preferred Number Series

The preferred number series was first proposed by a French engineer, Charles Renard (Booth 1967). The series usually used for wood is a geometric series with the common ratio between steps in the series based on the roots of 10. For example, if 5 steps are in each decade, then the common ratio of the geometric progression is $\sqrt[5]{10} = 1.5849$; if 10 steps, the common ratio is $\sqrt[10]{10} = 1.2589$, etc. The preferred number series has two distinct advantages. First, the series can be extended indefinitely by selecting the desired number of steps between decades and shifting the decimal point. Second, the increment between classes is set without favoritism towards a particular species or product line. This lack of favoritism has been found to be especially important when trying to set stress class boundaries for international standards. Details of the preferred number series are given in British Standard BS 2045 (Booth 1967). Standard BS 2045 recommends the use of four series, designated R5, R10, R20, and R40; the number following R indicates the number of steps in a decade (Table 1). Note that the difference between terms in the R5 series is ~60 percent; in the R10 series, ~25 percent; in the R20 series, ~12 percent; and in the R40 series, ~6 percent. The R10 series has usually been found to provide an acceptable compromise between accuracy and simplicity when establishing stress class systems. Also, note that flexibility can be obtained by taking every other term of the next higher series. Thus, every other term of the R20 series and every fourth term of the R40 series are also terms of the R10 series. This information may provide needed flexibility when trying to match a particular series to grade boundaries.

Table 1—Basic preferred number series[a]

R5	R10	R20	R40
1.00	1.00	1.00	1.00
			1.06
		1.12	1.12
			1.19
	1.25	1.25	1.25
			1.33
		1.40	1.40
			1.50
1.60	1.60	1.60	1.60
			1.70
		1.80	1.80
			1.90
	2.00	2.00	2.00
			2.12
		2.24	2.24
			2.36
2.50	2.50	2.50	2 50
			2.65
		2.80	2.80
			3.00
	3.15	3.15	3.15
			3.35
		3.55	3.55
			3.75
4.00	4.00	4.00	4.00
			4.25
		4.50	4.50
			4.75
	5.00	5.00	5.00
			5.30
		5.60	5.60
			6.00
6.30	6.30	6.30	6.30
			6.70
		7.10	7.10
			7.50
	8.00	8.00	8.00
			8.50
		9.00	9.00
			9.50
10.00	10.00	10.00	10.00

[a]Booth (1967).

Current Stress Class Systems

A document produced by the Timber Research and Development Association (TRADA 1985) for the United Nations Industrial Development Organization gives a thorough review of existing stress class systems in the world. This document mentions 15 systems and discusses 7 systems in detail. Since 1985, an additional system has been proposed in Eurocode 5.

This section concentrates on four systems: Australian, United Kingdom, the draft version of the International Standards Organization (ISO), and the proposed Eurocode 5.

Australian

Most modern stress class systems used throughout the world originated from the Australian system. In Australia, strength classification methods have evolved during the past 50 years. The original system was proposed in 1939 by Langlands and Thomas in the

Table 2—The Australian stress class system[a]

a. Stress levels

Property	Stress levels ($\times 10^3$ lb/in^2)											
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
MOR[b]	0.87	1.09	1.38	1.70	2.22	2.77	3.54	4.51	5.47	7.00	8.70	10.90
UTS	0.52	0.64	0.84	1.06	1.32	1.68	2.13	2.71	3.29	4.25	5.32	6.67
UCS	0.68	0.84	1.06	1.32	1.68	2.13	2.71	3.29	4.19	5.32	6.67	8.38
Shear	0.11	0.14	0.16	0.20	0.23	0.27	0.34	0.40	0.47	0.55	0.66	0.79
MOE, mean	650	750	850	1,000	1,100	1,300	1,500	1,750	2,000	2,300	2,700	3,100

b. Classification rules

Modulus of rupture	Modulus of elasticity	Ultimate compression stress	Assessed strength class
A_x	A_x	A_x-1	A_x
A_x	A_x+2	A_x+1	A_x+1
A_x	A_x-2	A_x-1	A_x-1

[a]SAA (1988).

[b]These values were converted to the characteristic values by multiplying the working stress values by (16/9) × (5/4) (Pearson 1965).

Handbook of Structural Timber and Design (Pearson 1965). It specified four stress classes labeled A, B, C, and D, with A being the strongest and D the weakest. Species were classified according to their property values for MOR, MOE, ultimate compression stress (UCS) parallel to the grain, shear, and ultimate tensile stress (UTS), as determined from tests on small, clear specimens. These classes were used successfully because the limits were not closely defined. In fact, only the average values for each class were given, and considerable judgment was used in grouping a species.

In 1951, Cooper demonstrated the merits of a geometric series for working stresses, and in 1958, the United Nations Food and Agriculture Organization (FAO) recommended the adoption of a geometric series with a ratio of 1.125 to 1 between terms (R20 series). This system was revised and expanded by Pearson in 1965. Pearson proposed taking every second term in the series recommended by FAO (therefore an R10 series), choosing the following set of basic stresses for the extreme fiber stress in bending: 10,000, 8,000, 6,300, 5,000, 4,000, 3,200, 2,500, 2,000, 1,600, 1,250, and 1,000 lb/in^2. The Australian system was again revised in 1973 by Kloot (Keating 1981).

Table 2 shows the current Australian stress class system (SAA 1988). The stress levels (Table 2a) are basic stress values converted to characteristic values. Characteristic values are defined as 5th percentile strength values at nominal 2- by 8-in. (actual 38- by 184-mm) dimensions, 20°C (68°F), and 65 percent relative humidity (12 percent MC). This system also contains some classification rules that may override the class assigned using MOR (Table 2b). If for example, a species makes class x for MOR and UTS but is two classes higher for MOE and one higher for UCS, the final class assignment is $x + 1$.

United Kingdom

The original United Kingdom system was given in the British Code of Practice CP 112 Part 2 (Tory 1979). Practice CP 112 used small, clear specimen test results and placed 14 softwoods into three groups designated S1, S2, and S3. It gave no recommendation for hardwood grouping. This grouping system differed from a true stress class system in that it did not allow for the higher grades of weaker species to be classified with the lower grades of a stronger species. In 1967, Booth took Cooper's (1951) and Pearson's (1965) results with the preferred number series and suggested that it would

Table 3—The British stress class system for dry timber[a]

a. Stress levels

Property	Stress levels ($\times 10^3$ lb/in^2)								
	B1	B2	B3	B4	B5	B6	B7	B8	B9
MOR[b]	1.00	1.46	1.88	2.66	3.55	4.44	5.33	6.22	7.28
UTS	0.73	0.89	1.14	1.60	2.13	2.67	3.20	3.74	4.38
UCS	1.24	1.88	2.42	2.81	3.10	4.45	5.16	5.87	6.94
Shear	0.07	0.10	0.10	0.10	0.15	0.22	0.25	0.29	0.33
MOE, mean	1,000	1,150	1,250	1,400	1,550	2,050	2,350	2,700	3,100

b. Classification rules

Species and grades are admitted to a stress class if their bending and tension strength values are equal to or greater than their respective class values, and if their values for MOE (minimum), MOE (mean), shear, and compression parallel-to-the-grain exceed 95 percent of the class values. (Fewell 1989).

[a]TRADA (1985).
[b]Values were converted to the characteristic values by multiplying the working stress values by 1/(0.563 × 0.724) (Fewell 1984).

also be advantageous if the sizes of timber followed a preferred series (Booth 1967). Booth discussed the merits of adopting the preferred number series for size and length, and he proposed a potential system for stress classification.

The current United Kingdom system, British Standard BS 5268 (TRADA 1985), however, departed from the preferred number approach. Tory noted that "a more subjective choice of class boundaries taking into account some of the commercial difficulties of species/grades could produce a more acceptable system" (Tory 1979). The United Kingdom system classifies timbers into nine strength classes, we designated B1 to B9 (Table 3). Strength classes B5 to B9 are primarily for the denser hardwoods and have stresses that continue to progress in a geometric series, following the Australian system. Strength levels in the lower, softwoods, portion of the stress class system (B1 to B4) are tailored to fit England's primary species and grades. This system includes classification rules that allow lumber to make the class associated with MOR and UTS if MOE, shear, and UCS are within 95 percent of their assigned class values (Table 3b).

ISO

The ISO system was developed from work in the CIB W18A committee and was adopted by the working group of ISO/TC 165 in 1983 (ISO 1988; TRADA 1985). The ISO technical committee relied heavily on the Australian system. For the MOR value, the ISO system is stated in terms of characteristic value of a nominal 2 by 8 rather than allowable properties as in the Australian and British standards (Table 4). This approach allows individual countries to apply their preferred factors to the characteristic value when calculating allowable properties. However, relationships between other properties are different than those of the Australian system.

The ISO system roughly follows an R10 series for MOR. Although this system was never adopted as a European Committee for Standardization (CEN) standard (Sunley 1979), its framework was used as the basis for the initial Eurocode 5 system. The ISO system also includes classification rules that allow certain properties to be below specification without having to reduce the stress class assignment (Table 4b). For example, compression strength may be one stress class lower than the class assigned based on tensile strength if the bending assignment is one class higher than tension (Table 4).

Eurocode 5

The Eurocode 5 stress class system (Fewell 1989) is in draft form and will not become final until 1992. However, recent revisions involve relatively minor changes, and the current draft is expected to be close to that eventually adopted. Eurocode 5 resulted from efforts by the European Economic Community (EEC) (also known as the Common Market and includes Belgium,

Table 4—The draft International Standards Organization (ISO) stress class system[a]

a. Stress levels

Property[b]	Stress levels ($\times 10^3$ lb/in^2)												
	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13
MOR	0.70	0.87	1.09	1.38	1.74	2.18	2.76	3.48	4.35	5.51	6.96	8.70	10.88
UTS	0.35	0.44	0.55	0.70	1.09	1.38	1.74	2.18	2.76	3.48	4.35	5.51	6.96
UCS	0.87	1.09	1.38	1.38	1.74	2.18	2.18	2.76	3.48	4.35	5.51	6.96	8.70
Shear	0.14	0.17	0.17	0.22	0.28	0.28	0.28	0.35	0.44	0.55	0.70	0.70	0.87
MOE, mean	490	610	690	850	970	1,100	1,220	1,520	1,720	1,930	2,440	3,040	3,860

b. Classification rules

Modulus of rupture	Ultimate tensile stress	Ultimate compression stress	Modulus of elasticity, mean	Classification
T_x	T_x	T_x	T_x	T_x
T_x	T_x	T_x-1	T_x+1	T_x
T_x+1	T_x	T_x-1	T_x-1	T_x

[a]ISO (1988).
[b]MOR, UTS, and UCS are at the characteristic value. MOE, mean is calculated by taking characteristic value for MOE and multiplying by 1.4 (TRADA 1985).

Denmark, France, Federal Republic of Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, and United Kingdom) to provide its 12 member countries with a unified, internal system of harmonized standards and regulations (Cooke 1988; Sunley 1979). This system also has evolved with time, and its roots can be traced to CIB-W18A committee work and ISO draft standards (Tory 1979; ISO 1988). The current Eurocode 5 stress class system has 12 stress classes (Table 5). Characteristic values are based on a 200-mm width and are specified at 20°C and 65 percent relative humidity (12 percent MC). Assignment to a stress class system is based on three properties: characteristic bending strength, characteristic density, and mean MOE. Assignment of additional properties is assumed from the stress class assignment. As with MSR lumber in the United States, more than one MOE level may be listed for a given MOR.

Discussion

Comparison of Systems

Table 6 compares the class boundaries of five stress class systems. Other than the number of stress levels available, the MOR levels assigned to the individual stress classes are reasonably consistent. As expected, the ISO system has the broadest range of stress levels. Eurocode 5 has an extra stress level at the 3,000-lb/in^2 level, with the next lower stress level shifted slightly downward. The top two stress levels of the United Kingdom system are also lower than those given in the ISO system.

For secondary properties, reasonable agreement exists between systems for UTS but less agreement for the other properties (Table 6). Shear strength values in the Australian system tend to parallel those values used in the United Kingdom system but differ from those values assumed in the ISO and Eurocode 5 systems. In most cases, the differences in property assumptions are due to inherently different assumptions of property relationships. Unfortunately, the data bases used for these assumptions were not always documented in published literature.

Most of the systems apparently assume a UTS/MOR ratio of about 0.6 when determining class boundaries for UTS (Fig. 2). This ratio agrees with average values found with In-Grade data adjusted to 15 percent MC (Green and Kretschmann 1989, [in press]) and with data collected by Curry and Fewell (1977) at about

Table 5—Eurocode 5 stress class system, March 1989[a]

Property	Stress levels											
	C13–7E	C15–8E	C15–11E	C18–9E	C21–10E	C21–13E	C24–11E	C30–12E	C30–15E	C37–14E	C48–20E	C60–22E
MOR ($\times 10^3$ lb/in^2)	1.9	2.2	2.2	2.6	3.0	3.0	3.5	4.4	4.4	5.4	7.0	8.7
MOE mean parallel to grain ($\times 10^6$ lb/in^2)	1.0	1.2	1.6	1.3	1.5	1.9	1.6	1.7	2.2	2.0	2.9	3.2
Specific gravity (ovendried)	0.29	0.29	0.42	0.32	0.33	0.45	0.35	0.39	0.49	0.42	0.57	0.67
UTS parallel to grain ($\times 10^3$ lb/in^2)	1.2	1.3	1.3	1.6	1.9	1.9	2.0	2.6	2.6	3.2	4.2	5.2
Tension perpendicular to grain ($\times 10^3$ lb/in^2)	0.04	0.04	0.04	0.04	0.06	0.06	0.06	0.06	0.06	0.06	0.09	0.10
UCS perpendicular to grain ($\times 10^3$ lb/in^2)	2.3	2.5	2.5	2.8	2.9	2.9	3.0	3.5	3.5	4.1	5.1	5.8
Compression perpendicular to grain ($\times 10^3$ lb/in^2)	0.70	0.70	0.75	0.75	0.78	0.83	0.83	0.91	0.97	0.97	1.3	1.5
Shear ($\times 10^3$ lb/in^2)	0.23	0.25	0.25	0.26	0.30	0.30	0.35	0.44	0.44	0.54	0.70	0.87
MOE minimum parallel to grain ($\times 10^6$ lb/in^2)	0.71	0.80	1.1	0.9	1.0	1.3	1.1	1.2	1.49	1.45	2.03	2.18
MOE mean perpendicular to grain (softwood) ($\times 10^6$ lb/in^2)	0.03	0.04	0.05	0.04	0.05	0.06	0.05	0.06	0.07	0.07	—	—
MOE mean perpendicular to grain (hardwood) ($\times 10^6$ lb/in^2)	0.07	0.08	0.11	0.09	0.10	0.12	0.11	0.12	0.15	0.13	0.19	0.22
Shear modulus mean ($\times 10^6$ lb/in^2)	0.06	0.07	0.10	0.08	0.09	0.12	0.10	0.11	0.13	0.12	0.17	0.20

[a] Fewell (1989).

Table 6—Comparison of Australian, United Kingdom, ISO, Eurocode 5, and United States stress class systems

Property and stress class system[a]	Stress levels ($\times 10^3$ lb/in^2)														
MOR															
Australian	—	0.9	1.1	1.4	1.8	2.2	2.8	—	3.5	4.4	—	5.5	7.0	8.7	10.9
United Kingdom	—	—	1.0	1.5	1.9	—	2.7	—	3.6	4.4	—	5.3	6.2	7.3	—
ISO	0.7	0.9	1.1	1.4	1.7	2.2	2.8	—	3.5	4.4	—	5.5	7.0	8.7	10.9
Eurocode 5	—	—	—	1.9	2.2	2.6	3.0	3.5	4.4	—	5.4	7.0	8.7	—	
United States	0.4	—	0.9	1.4	1.7	2.2	3.0	—	3.5	4.4	4.9	5.5	7.0	8.7	—
UTS															
Australian	—	0.5	0.7	0.8	1.1	1.3	1.7	—	2.1	2.7	—	3.4	4.3	5.3	6.7
United Kingdom	—	—	0.7	0.9	1.1	—	1.6	—	2.1	2.7	—	3.2	3.7	4.4	—
ISO	0.3	0.4	0.6	0.7	1.1	1.4	1.7	—	2.2	2.8	—	3.5	4.4	5.5	7.0
Eurocode 5	—	—	—	—	1.2	1.3	1.6	1.9	2.0	2.6	—	3.2	4.1	5.1	5.8
United States	0.2	—	0.5	0.8	1.1	1.3	1.8	—	2.1	2.6	2.9	3.3	4.2	5.2	—
UCS															
Australian	—	0.7	0.8	1.1	1.3	1.7	2.1	—	2.7	3.4	—	4.2	5.3	6.6	8.4
United Kingdom	—	—	1.2	1.8	2.4	—	2.8	—	3.1	4.4	—	5.2	5.9	6.9	—
ISO	0.9	1.1	1.4	1.4	1.7	2.2	2.2	—	2.8	3.5	—	4.4	5.5	7.0	8.7
Eurocode 5	—	—	—	—	2.3	2.5	2.8	2.9	3.0	3.5	—	4.1	5.1	5.8	—
United States	0.6	—	1.3	1.8	2.0	2.4	2.7	—	2.9	3.0	3.1	3.2	3.6	4.4	—
Shear															
Australian	—	0.05	0.06	0.08	0.09	0.10	0.12	—	0.15	0.18	—	0.21	0.25	0.30	0.36
United Kingdom	—	—	0.07	0.10	0.10	—	0.10	—	0.15	0.22	—	0.25	0.29	0.33	—
ISO	0.14	0.17	0.17	0.22	0.28	0.28	0.28	—	0.35	0.44	—	0.55	0.70	0.70	0.87
Eurocode 5	—	—	—	—	0.23	0.25	0.26	0.30	0.35	0.44	—	0.54	0.70	0.87	—
United States	0.22	—	—	—	—	0.28	—	—	—	0.36	—	—	—	—	—
MOE, mean															
Australian	—	650	750	850	1,000	1,100	1,300	—	1,500	1,750	—	2,000	2,300	2,700	3,100
United Kingdom	—	—	1,000	1,150	1,250	—	1,400	—	1,550	2,050	—	2,350	2,700	3,100	—
ISO	490	610	690	850	970	1,100	1,220	—	1,520	1,720	—	1,930	2,440	3,040	3,860
Eurocode 5	—	—	—	—	1,000	1,200	1,300	1,450	1,600	1,700	—	2,000	2,900	3,200	—
United States	500	—	700	850	1,100	1,300	—	1,500	1,800	1,900	2,100	2,600	3,100	—	—

[a]MOR, UTS, and UCS are at the 5th percentile of 2 by 8 lumber. Greater MOE values are also available in the Eurocode 5 system at MOR levels of 2.2, 3.0, and 4.4 $\times 10^3$ lb/in^2; —, no corresponding value.

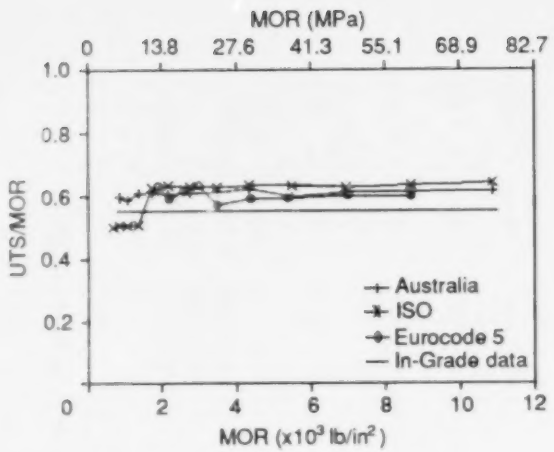

Figure 2—Relationship of ultimate tensile stress (UTS) to modulus of rupture (MOR) for 2- by 8-in. lumber at 12-percent moisture content.

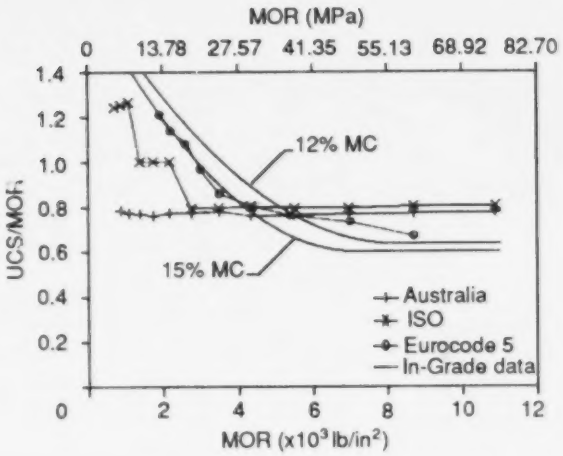

Figure 3—Relationship of ultimate compression stress (UCS) to modulus of rupture (MOR) for 2- by 8-in. lumber at 12-percent moisture content (except as indicated).

15 percent MC. However, In-Grade data adjusted to 12 percent have a UTS/MOR ratio closer to 0.55 (Fig. 2). For the lowest stress levels, the ISO system assumes a UTS/MOR ratio of only about 0.50.

Eurocode 5 uses two relationships to relate UCS to MOR. The primary relationship is that inherent in the stress class boundaries (Fig. 3). When test data on structural size members were not available for UCS, a relationship based on the work of Curry and Fewell (1977) was used (Glos and Fewell 1989). The Curry and Fewell relationship was based on data in which the actual moisture content of lumber at time of test was 18 percent for UCS and 15 percent for MOR. The In-Grade data at 15 percent MC closely follow data presented by Curry and Fewell (Green and Kretschmann 1989, [in press]). The In-Grade data adjusted to 12 percent MC yield a higher UCS/MOR ratio than that inherent in the Eurocode 5 boundaries (Fig. 3). For MOR values greater than about 4,000 lb/in^2, the Eurocode 5 UCS/MOR ratio is higher than that of the In-Grade data adjusted to 15 percent. For values less than 4,000 lb/in^2, the two curves coincide. The ISO and Australian systems assume a UCS/MOR ratio inconsistent with either the Curry and Fewell or the In-Grade data. The Australian system assumes a constant UCS/MOR ratio of about 0.77.

Relationships between MOE and MOR assumed in stress class systems are based on mean MOE and 5th percentile MOR, rather than on mean trends. Except for the alternative class levels available in the Eurocode 5 system and the top three class levels of the Australian system, these relationships approximate the relationship traditionally used with MSR lumber in the United States (Fig. 4). The In-Grade data trends parallel those traditionally assumed for MSR lumber (Green and Kretschmann 1989, [in press]).

The relationships for shear strength parallel to the grain and MOR inherent in the Australian, ISO, and Eurocode 5 stress class systems are shown in Figure 5. Again, significant differences are apparent at certain MOR levels.

Advantages

Experience with stress class systems, such as those previously described, indicates that they offer a number of advantages.

Species Independent—For most properties, the system is species independent for hardwoods and softwoods. Thus, stress class systems focus attention on the use of the material, not on which species is being used.

Simple—The system greatly reduces the alternatives that an engineer must consider when designing with wood. This is especially useful when making "first pass" design estimates.

Permanent—The system does not have to be changed every time a change occurs in grading procedures, when new technical data become available, or when new species are added.

Grading-system independent—The stress class system is not dependent upon the method used to sort lumber

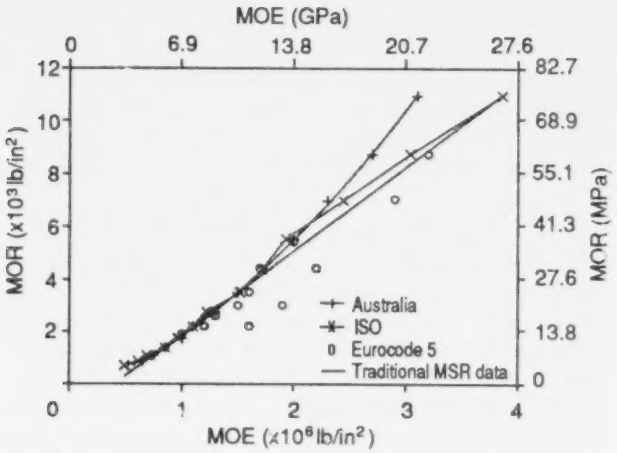

Figure 4—Relationship of modulus of rupture (MOR) to modulus of elasticity (MOE) for 2- by 8-in. lumber at 12-percent moisture content.

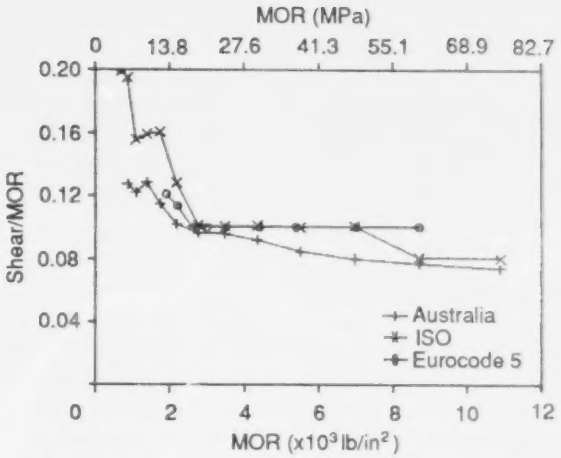

Figure 5—Relationship of shear stress parallel to the grain (sheer) to modulus of rupture (MOR) for 2- by 8-in. lumber at 12-percent moisture content.

into the classes. It is only necessary that the lumber have the specified properties.

Performance oriented—Performance, not grades, are the focus of the system. Thus, a stress class system focuses attention on the competition between wood and other building materials, rather than on the competition between lumber products.

Product independent—This system does not depend on the end product and applies both to solid-sawn lumber and to engineered composite lumber.

Familiar—Stress class systems are familiar to lumber users in Europe, Australia, and England. A U.S. stress class system could encourage the use of U.S. lumber in other parts of the world.

Reliable—In a stress class system, the emphasis is on achieving specified properties, not grade description.

Nonrevolutionary—A stress class system does not replace existing grading systems. Thus, the producer is free to use the system only if it provides an economic advantage.

Disadvantages

Experience also indicates some disadvantages with stress class systems.

Inefficient for some properties—Stress class systems optimize a particular property. It is not possible to optimize all properties assigned to a given stress class. Thus, the system incorporates some inefficiency in the design process. However, the inefficiency is generally less than that encountered when grouping species using American Society of Testing Materials (ASTM) standards.

Not totally species independent—Some properties do not relate well to the stress class system. Two obvious examples are durability and nail-holding capacity. Thus, if these properties are critical for a particular application, it may still be necessary to specify a particular species or species group.

No universally accepted stress class system—Although stress class systems have been used for a number of years, no one system has come into general use throughout the world. Each country has usually developed systems that optimize properties for species important in their countries.

Evaluation and Development of Stress Class Systems

We envision that a stress class system developed for use in the United States should apply to lumber products, solid-sawn and composite, whether hardwood or softwood. It is not clear whether a stress class system would be more useful for those grades and sizes normally used for light-frame structures or whether the system would be more useful for lumber intended for the industrial and commercial market. Therefore, stress class systems proposed in this report cover a wide range of properties sufficient for all potential uses and products. For consistency with other stress class systems in use, all stress class systems given in this report are based on a "characteristic value" (5th percentile or mean value not divided by a general adjustment factor)

of a nominal 2 by 8. For bending, the test length is at a span-to-depth ratio of 17:1.

Mean specific gravity values given in Tables 7 and 8 are from values listed in the NDS (NFPA 1986). These values are based on weight and volume in the ovendry condition. These values agree well with the values obtained for lumber tested in the In-Grade Testing Program (Green and Evans 1989).

Evaluation

Import and export of lumber could be facilitated if the United States were to adopt one of the existing stress class systems. One consideration in choosing an existing system is U.S. lumber exports. In the first half of 1988, 55 percent of U.S. lumber exports went to Pacific Rim countries, principally Japan, and 23 percent went to EEC countries. (Table 9). However, these percentages varied significantly with species. Therefore, it is not possible to select one specific existing stress class system. The existing systems we evaluate in this report are the Australian, the draft ISO, and the Eurocode 5. The United Kingdom system is not considered, because it is assumed that it will eventually be replaced by the Eurocode 5 system.

Some systems discussed also contain classification rules that may override the stress class assigned using the primary property. To evaluate the contribution of the classification rules to stress class assignment, we first evaluated the system without using the rules. Then, we determined if the classification rules were useful in preventing a loss in stress class assignment.

Australian

Application of the Australian system (Table 2) to the characteristic values shown in Table 8 indicates that for visually graded lumber, in several instances, secondary properties fail to make the assigned stress class based on MOR (Table 10). The primary problem is with the UTS assignment. This is because the UTS/MOR ratio assumed in the Australian standard is slightly higher than that found with the In-Grade data at 12 percent MC. In addition, the Australian code uses an average relationship, thus, you would expect about half of any experimental data to be slightly below the average trend line.

For MSR lumber, a consistent problem with the values currently assigned is the first three UTS assignments (Table 10). This is a result of the nonconstant UTS/MOR relationship assumed for MSR lumber in the United States (Green and Kretschmann [in press]). Other grades occasionally fail to make a stress class assignment. Of the composite lumber products, only the MOE assignment of the Gang-lam[1] product seems to present a consistent problem.

With the Australian system, the classification rules did not prevent stress class reductions (Table 10). This was because either the limiting situation was not covered by the rules or another property limited the stress class.

ISO

For visually graded lumber, the primary problem with the ISO system is failure to make the assigned UTS value (Table 11). As with the Australian system, this is the result of assuming a slightly higher average trend line between UTS/MOR and MOR. For grades limited by UTS, the classification rules provide no opportunity to increase the stress class.

With MSR lumber, consistent problems occurred with UTS and UCS for the four lowest grades. This is due to the low UTS and UCS values assigned these grades of MSR lumber. In this case, neither the trends assumed by the ISO system nor the constant UCS/MOR ratio of 0.72 × MOR assumed for MSR lumber appears to follow those observed in the In-Grade data (Fig. 3). Classification rules again provide no help in resolving problems with class assignments.

For composite lumber, only one product had difficulty making the assigned stress class. Again, the classification rules do not prevent this UCS value from limiting the final stress class assignment.

Eurocode 5

For visually graded lumber, several UTS values fall below the stress class assigned by Eurocode 5 (Table 12). As previously noted, assumption of a lower UTS/MOR ratio in the Eurocode 5 system would have eliminated these problems.

As expected, UTS and UCS assignments for MSR lumber have several problems, (Fig. 2 and 3). First, Eurocode 5 does not have stress classes as low as required for the lowest grade of MSR lumber (Table 12). In addition, several lower grades of MSR lumber have UTS assignments below those assumed in Eurocode 5. Most UCS values assigned to MSR lumber meet the properties required by the Eurocode 5 system. This is because MSR lumber currently assumes a constant UCS/MOR ratio of about 0.72. Note, however, that the UCS/MOR relationships currently assumed for MSR lumber are also not consistent with experimental

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Table 7—Alternate values for specific gravity, compression perpendicular (C-Perp) to the grain, and shear parallel to the grain

Group	Species	Mean specific gravity[a] (ovendried)	C-Perp (lb/in^2)	Shear (lb/in^2)
I	Ash, Commercial White	0.62	—	—
	Beech	0.68	1,200	410
	Birch, Sweet and Yellow	0.66	1,200	410
	Hickory and Pecan	0.75	1,200	410
	Maple, Black and Sugar	0.66	1,050	410
	Oak, Red and White	0.67	1,350	350
II	Douglas Fir–Larch	0.51	1,050	390
	Southern Pine	0.55	945	410
	Sweetgum and Tupelo	0.54	—	—
	Virginia Pine–Pond Pine	0.54	945	370
III	California Redwood	0.42	1,100	330
	Douglas Fir, South	0.48	870	370
	Eastern Hemlock	0.43	920	350
	Eastern Hemlock–Tamarack	0.45	925	350
	Eastern softwoods	0.42	560	290
	Hem–Fir	0.42	675	290
	Lodgepole Pine	0.44	670	290
	Mountain Hemlock	0.47	950	390
	Mountain Hemlock–Hem Fir	0.44	675	310
	Northern Aspen	0.42	535	250
	Northern Pine	0.46	725	290
	Ponderosa Pine	0.49	895	290
	Ponderosa Pine–Sugar Pine	0.42	625	290
	Red Pine	0.42	735	290
	Sitka Spruce	0.43	725	310
	Southern Cypress	0.48	—	—
	Spruce–Pine–Fir	0.42	710	290
	Western Hemlock	0.48	685	370
	Yellow Poplar	0.46	700	310
IV	Aspen	0.40	440	250
	Balsam Fir	0.36	510	290
	Black Cottonwood	0.33	300	200
	California Redwood, open grain	0.37	710	330
	Coast Sitka Spruce	0.39	760	270
	Coast Species	0.39	620	270
	Cottonwood, Eastern	0.41	535	270
	Eastern Spruce	0.41	650	290
	Eastern White Pine	0.38	585	290
	Eastern Woods	0.36	450	250
	Engelmann Spruce–Alpine Fir	0.36	535	290
	Idaho White Pine	0.40	525	290
	Northern Species	0.35	585	270
	Northern White Cedar	0.31	620	270
	West Coast Woods (mixed species)	0.35	525	290
	Western Cedars	0.35	710	310
	Western White Pine	0.40	625	270
	White Woods	0.35	525	290

[a]NFPA (1986).

Table 8—Characteristic and mean values for lumber[a]

Product	Lumber grade	Mean MOR ($\times 10^3$ lb/in^2)	Mean MOE ($\times 10^6$ lb/in^2)	Mean UTS ($\times 10^3$ lb/in^2)	Mean UCS ($\times 10^3$ lb/in^2)	Specific gravity[b] 5th percentile (ovendried)	Specific gravity[b] Mean
Visually stress rated, 12 percent MC[c]							
Douglas Fir	S.S.	4.367	1.915	2.605	3.784	0.41	0.51
Southern Pine		5.392	1.922	2.612	4.076	0.44	0.55
Hem-Fir		3.977	1.608	2.327	3.369	0.35	0.42
Canadian Spruce-Pine-Fir		3.363	1.549	1.723	3.134	0.34	0.42
Douglas Fir (South)		3.506	1.405	2.277	3.772	0.38	0.48
(Minor) Southern Pine		3.954	1.699	2.071	3.525	0.43	0.54
Douglas Fir (North)		3.603	1.908	2.026	4.320	0.41	0.51
Hem-Fir (North)		3.484	1.774	1.957	3.721	0.34	0.42
Douglas Fir	No. 2	2.510	1.620	1.487	2.807	0.41	0.51
Southern Pine		2.654	1.637	1.379	2.993	0.44	0.55
Hem-Fir		2.324	1.380	1.356	2.643	0.35	0.42
Canadian Spruce-Pine-Fir		2.366	1.421	1.108	2.513	0.34	0.42
Douglas Fir (South)		2.436	1.258	1.249	2.802	0.38	0.48
(Minor) Southern Pine		2.351	1.419	1.248	2.815	0.43	0.54
Douglas Fir (North)		2.211	1.648	1.230	3.046	0.51	0.51
Hem-Fir (North)		2.619	1.637	1.359	3.134	0.34	0.42
Visually stress rated, (15 percent MC)							
Douglas Fir	S.S.	4.427	1.828	2.774	3.413	0.41	0.51
Southern Pine		5.400	1.835	2.779	3.664	0.44	0.55
Hem-Fir		4.023	1.535	2.479	3.029	0.35	0.42
Canadian Spruce-Pine-Fir		3.425	1.479	1.835	2.874	0.54	0.42
Douglas Fir (South)		3.557	1.341	2.413	3.377	0.38	0.48
(Minor) Southern Pine		3.996	1.622	2.189	3.174	0.43	0.54
Douglas Fir (North)		3.684	1.822	2.152	3.911	0.41	0.51
Hem-Fir (North)		3.568	1.694	2.092	3.439	0.34	0.42
Douglas Fir	No. 2	2.590	1.547	1.613	2.646	0.41	0.51
Southern Pine		2.740	1.563	1.496	2.813	0.44	0.55
Hem-Fir		2.394	1.318	1.471	2.460	0.35	0.42
Canadian Spruce-Pine-Fir		2.399	1.357	1.200	2.383	0.34	0.42
Douglas Fir (South)		2.507	1.201	1.354	2.617	0.38	0.48
(Minor) Southern Pine		2.422	1.355	1.350	2.699	0.43	0.54
Douglas Fir (North)		2.275	1.573	1.332	2.907	0.51	0.51
Hem-Fir (North)		2.702	1.563	1.472	2.974	0.34	0.42

Table 8—Characteristic and mean values for lumber[a]–con.

Product	Lumber grade	Mean MOR ($\times 10^3$ lb/in^2)	Mean MOE ($\times 10^6$ lb/in^2)	Mean UTS ($\times 10^3$ lb/in^2)	Mean UCS ($\times 10^3$ lb/in^2)	Specific gravity[b] 5th percentile (ovendried)	Specific gravity[b] Mean
Machine stress rated[d]	900f-1.0E	1.890	1.000	0.735	1.378	–	–
	1200f-1.2E	2.520	1.200	1.266	1.805	–	–
	1350f-1.3E	2.835	1.300	1.575	2.012	–	–
	1450f-1.3E	3.045	1.300	1.680	2.185	–	–
	1500f-1.3E	3.150	1.300	1.896	2.280	–	–
	1500f-1.4E	3.150	1.400	1.896	2.280	–	–
	1650f-1.5E	3.465	1.500	2.142	2.508	–	–
	1800f-1.6E	3.780	1.600	2.468	2.755	–	–
	1950f-1.7E	4.095	1.700	2.888	2.945	–	–
	2100f-1.8E	4.410	1.800	3.308	3.230	–	–
	2250f-1.6E	4.725	1.600	3.675	3.420	–	–
	2250f-1.9E	4.725	1.900	3.675	3.420	–	–
	2400f-2.0E	5.145	2.000	4.042	3.658	–	–
	2550f-2.1E	5.355	2.100	4.305	3.895	–	–
	2700f-2.2E	5.670	2.200	4.515	4.085	–	–
	2850f-2.3E	5.985	2.300	4.830	4.370	–	–
	3000f-2.4E	6.300	2.400	5.040	4.560	–	–
	3150f-2.5E	6.615	2.500	5.250	4.750	–	–
	3300f-2.6E	6.930	2.600	5.565	5.035	–	–
Composite lumber[c]							
Arrowood	—	4.095	1.500	–	–	–	–
Lamineer	22f	4.947	2.200	4.186	4.940	–	–
Microlam	2.2E	6.900	2.200	4.305	5.415	–	–
	2.0E	6.233	2.000	3.885	5.130	–	–
	1.8E	5.120	1.800	3.465	4.560	–	–
Paralam	—	6.455	2.000	5.040	5.510	–	–
Gang-lam	4250-2.4E	9.460	2.400	6.825	6.365	–	–
	3200-2.2E	7.123	2.200	5.460	5.938	–	–
	3100-1.8E	6.900	1.800	4.935	4.959	–	–

[a]Characteristic strengths in this report are normalized nonparametric point estimate percentiles. Values adjusted to 2- by 8-in. lumber using (W1/W2) × (1/2.8) (Green and Evans 1989). Compression parallel values for U.S. species have been reduced 5 percent (Green and Kretschmann [in press]). MOE is a mean value.

[b]For visually stress rated lumber, 5th percentile specific gravity equals mean value × 0.80, Table 15. Specific gravity for MSR lumber depends upon the species.

[c]Green and Evans (1987) and Canadian Wood Council (1988).

[d]NFPA (1986).

[e]Gang-Nail Systems, Inc. (1985); MacMillian–Bloedel Limited (1986); Fiberboard Technologies (1990); Trus Joist Corporation (1983); Weyerhaeuser Company (1980).

Table 9—U.S. lumber exports for the first half of 1988[a]

Region	Total exports ($\times 10^3$ board feet)			Exports as percentage of total		
	Hemlock	Douglas Fir	Southern Pine	Hemlock	Douglas Fir	Southern Pine
European Economic Community	14,368	94,961	117,259	4.1	23.8	53.9
Pacific Rim	321,950	221,653	2,830	90.8	55.5	1.3
Central and South America	180	2,109	66,233	0.1	0.5	30.4
Other	18,012	80,575	31,425	5.0	20.2	14.4
Total	354,510	399,298	217,747	100.0	100.0	100.0

[a]Information supplied by National Forest Products Association and Southern Forest Products Association from offical U.S. Department of Commerce statistics.

evidence (Green and Kretschmann [in press]). Thus, it seems possible to revise property assignments to bring all but the lowest grades of MSR lumber in line with Eurocode 5 UCS assignments (Green and Kretschmann 1989).

The composite lumber products listed in Table 12 appear to have no problem making the Eurocode 5 assignments.

Developing An Alternative System

As previously discussed, MOR and MOE stress class boundaries for the ISO, Eurocode 5, and Australian systems are reasonably consistent. However, inconsistencies do occur between UCS/MOR and UTS/MOR ratios determined from experimental data and those inherent in the stress class boundaries of these systems. For these reasons, we propose an alternative stress class system based on ISO and Eurocode 5 class boundaries for MOR and MOE, but using experimental-based relationships to determine UCS and UTS (Table 13).

The proposed stress class system would ideally be based on environmental conditions corresponding to a moisture content of approximately 12 percent. However, design values in the United States have traditionally focused on a moisture content of 15 percent. The desire of the lumber industry to maintain the 15 percent reference base has recently been reconfirmed in ASTM and reliability-based design deliberations. Thus, our proposed system is based on conditions corresponding to a moisture content of approximately 15 percent. As we have shown, the experimental UCS/MOR and UTS/MOR relationships at 15 percent MC more closely match the relationships used in Eurocode 5 than the experimental relationships at 12 percent MC.

Our proposed system contains a wide range of stress classes. This was done to ensure that the system would be applicable to the lowest grades of visually graded lumber as well as the highest grades of machine-graded solid-sawn lumber and composite lumber products. The UTS/MOR ratio was fixed at 0.60. The following UCS/MOR ratio is from Green and Kretschmann [in press]:

If ($MOR < 7.2 \times 10^3$ lb/in^2),

$$UCS/MOR = 1.745 - (0.32 \times MOR) + (0.0223 \times MOR^2)$$

If ($MOR \geq 7.2 \times 10^3$ lb/in^2),

$$USC/MOR = 0.596$$

Compression perpendicular (C-Perp) and shear values were determined by comparison with allowable properties derived from clear wood data.

Classification of In-Grade data by the proposed system is presented in Table 14. The proposed system results in most No. 2 grade lumber being assigned to stress class 5. We feel this is an advantageous design simplification for engineers making preliminary design estimates. Select Structural lumber is assigned several stress classes based on species differences. For visually graded lumber, occasional failures of secondary properties to make stress class assignments based on MOR values could be handled by slight adjustments in assumed property ratios. However, such decisions should be made by consensus standards organizations.

This alternative stress class system does not treat the UCS of MSR lumber favorably. This is primarily because current procedures for deriving allowable properties of MSR lumber assume a constant UCS/MOR ratio of 0.72 (Fc/Fb of 0.80).[2] Some problems are also noted in the UTS assignment for some of the lower grades.

[2] Allowable compression strength Fc = UCS/1.9; allowable bending strength Fb = MOR/2.1.

Table 10—Stress class assignment for North American lumber using the Australian System[a]

Product	Grade	Stress class assignment			
		MOR	MOE	UTS	UCS
Visually stress rated					
Douglas Fir	S.S.	A7	A8	A7	A8
Southern Pine		A8	A8	A7?	A8
Hem–Fir		A7	A7	A7	A8
Canadian Spruce–Pine–Fir		A6	A7	A6	A7
Douglas Fir (South)		A6	A6	A7	A8
(Minor) Southern Pine		A7	A7	A6?	A8
Douglas Fir (North)		A7	A8	A6?	A9
Hem–Fir (North)		A6	A8	A6	A8
Douglas Fir	No. 2	A5	A7	A5	A7
Southern Pine		A5	A7	A5	A7
Hem–Fir		A5	A6	A5	A6
Canadian Spruce–Pine–Fir		A5	A6	A4?	A6
Douglas Fir (South)		A5	A5	A4?	A7
(Minor) Southern Pine		A5	A6	A4?	A7
Douglas Fir (North)		A4	A7	A4	A7
Hem–Fir (North)		A5	A7	A5	A7
Machine stress rated					
	900f-1.0E	A4	A4	A2?	A4
	1200f-1.2E	A5	A5	A4?	A5
	1350f-1.3E	A6	A6	A5?	A5?
	1450f-1.3E	A6	A6	A6	A6
	1500f-1.3E	A6	A6	A6	A6
	1500f-1.4E	A6	A6	A6	A6
	1650f-1.5E	A6	A7	A7	A6
	1800f-1.6E	A7	A7	A7	A7
	1950f-1.7E	A7	A7	A8	A7
	2100f-1.8E	A7	A8	A9	A7
	2250f-1.6E	A8	A7?	A9	A8
	2250f-1.9E	A8	A8	A9	A8
	2400f-2.0E	A8	A9	A9	A8
	2550f-2.1E	A8	A9	A10	A8
	2700f-2.2E	A9	A9	A10	A8?
	2850f-2.3E	A9	A10	A10	A9
	3000f-2.4E	A9	A10	A10	A9
	3150f-2.5E	A9	A10	A10	A9
	3300f-2.6E	A9	A10	A11	A9
Composite lumber					
Arrowood	—	A7	A7	—	—
Lamineer	22f	A8	A9	A9	A9
Microlam	2.2E	A9	A9	A10	A10
	2.0E	A9	A9	A9	A9
	1.8E	A8	A8	A9	A9
Paralam	—	A9	A9	A10	A10
Gang–lam	4250f-2.4E	A11	A10?	A12	A10?
	3200f-2.2E	A10	A9?	A11	A10
	3100-1.8E	A9	A8?	A10	A9

[a]? indicates a stress class level that does not make the primary property stress class level. Classification rules are of no help.

Table 11—Stress class assignment for North American lumber using the ISO system[a]

Product	Grade	Stress class assignment				Classification rules[b]
		MOR	MOE	UTS	UCS	
Visually stress rated						
Douglas Fir–Larch	S.S.	I9	I9	I8?	I9	–
Southern Pine		I9	I9	I8?	I9	–
Hem–Fir		I8	I8	I8	I8	–
Canadian Spruce–Pine–Fir		I7	I8	I6?	I8	–
Douglas Fir (South)		I8	I7	I8	I9	–
(Minor) Southern Pine		I8	I8	I7?	I9	–
Douglas Fir (North)		I8	I9	I7?	I9	–
Hem–Fir (North)		I8	I9	I7?	I9	–
Douglas Fir–Larch	No. 2	I6	I8	I6	I8	–
Southern Pine		I6	I8	I5	I8	–
Hem–Fir		I6	I7	I5?	I7	–
Canadian Spruce–Pine–Fir		I6	I7	I5?	I7	–
Douglas Fir(South)		I6	I7	I5?	I8	–
(Minor) Southern Pine		I6	I7	I5?	I8	–
Douglas Fir (North)		I6	I8	I5?	I8	–
Hem–Fir (North)		I6	I8	I5?	I8	–
Machine stress rated						
	900-1.0E	I5	I5	I4?	I2?	–
	1200-1.2E	I6	I6	I5?	I5?	–
	1350-1.3E	I7	I7	I6?	I5?	+
	1450-1.3E	I7	I7	I6?	I7	–
	1500-1.3E	I7	I7	I7	I7	+
	1500-1.4E	I7	I7	I7	I7	+
	1650-1.5E	I7	I7	I7	I7	–
	1800-1.6E	I8	I8	I8	I7?	+
	1950-1.7E	I8	I8	I9	I8	+
	2100-1.8E	I9	I9	I9	I8?	+
	2250-1.6E	I9	I8?	I10	I8?	–
	2250-1.9E	I9	I9	I10	I8?	+
	2400-2.0E	I9	I10	I10	I9	–
	2550-2.1E	I9	I10	I10	I9	–
	2700-2.2E	I10	I10	I11	I9?	+
	2850-2.3E	I10	I10	I11	I10	+
	3000-2.4E	I10	I10	I11	I10	–
	3150-2.5E	I10	I11	I11	I10	–
	3300-2.6E	I10	I11	I12	I10	–
Composite lumber						
Arrowood	—	I8	I8	—	—	
Lamineer	22f	I9	I10	10	I10	–
Microlam	2.2E	I10	I10	I10	I10	–
	2.0E	I10	I10	I10	I10	–
	1.8E	I9	I9	I9	I10	–
Paralam	—	I10	I10	I11	I11	–
Gang-lam	4250-2.4E	I12	I10?	I12	I11?	–
	3200-2.2E	I11	I10?	I11	I11	–
	3100-1.8E	I10	I9	I11	I10	–

[a] ? indicates a stress class level that does not make the primary property stress class level.
[b] –, no help; +, helped.

Table 12—Stress class assignment for North American lumber using the Eurocode 5 system[a]

Product	Grade	MOR classs level	MOE classs level	Density limited[b]	Stress class assignment[c]	UTS stress level	UCS stress level
Visually stress rated							
Douglas Fir–Larch	S.S.	C24	13E	No	C24-11E	C30	C30
Southern Pine		C30	13E	No	C30-12E	C30	C30
Hem–Fir		C24	11E	No	C24-11E	C24	C24
Canadian Spruce–Pine–Fir		C21	10E	No	C21-10E	C18?	C24
Douglas Fir (South)		C24	9E	No	C18-9E	C24	C30
(Minor) Southern Pine		C24	11E	No	C24-11E	C24	C30
Douglas Fir (North)		C24	13E	No	C24-11E	C24	C37
Hem–Fir (North)		C21	12E	No	C21-10E	C21	C30
Douglas Fir	No. 2	C15	11E	Yes	C15-8E	C15	C18
Southern Pine		C18	11E	No	C18-9E	C15?	C21
Hem–Fir		C15	9E	No	C15-8E	C15	C15
Canadian Spruce–Pine–Fir		C15	9E	No	C15-8E	Below	C15
Douglas Fir (South)		C15	8E	No	C15-8E	C13?	C18
(Minor) Southern Pine		C15	9E	No	C15-8E	C13?	C18
Douglas Fir (North)		C15	11E	No	C15-11E	C13?	C24
Hem–Fir (North)		C18	11E	No	C18-9E	C15?	C24
Machine stress rated							
	900f-1.0E	Below	7E	–	Below	Below	Below
	1200f-1.2E	C15	8E	–	C15-8E	C13?	Below
	1350f-1.3E	C18	9E	–	C18-9E	C15?	Below
	1450f-1.3E	C21	9E	–	C18-9E	C18	Below
	1500f-1.3E	C21	9E	–	C19-9E	C18?	Below
	1500f-1.4E	C21	10E	–	C21-10E	C18?	Below
	1650f-1.5E	C21	11E	–	C21-10E	C24	C15?
	1800f-1.6E	C24	11E	–	C24-11E	C24	C15?
	1950f-1.7E	C24	12E	–	C24-11E	C30	C21?
	2100f-1.8E	C30	12E	–	C30-12E	C37	C24?
	2250f-1.6E	C30	11E	–	C24-11E	C37	C24?
	2250f-1.9E	C30	13E	–	C30-12E	C37	C24?
	2400f-2.0E	C30	14E	–	C30-12E	C37	C30
	2550f-2.1E	C30	14E	–	C30-12E	C48	C30
	2700f-2.2E	C37	15E	–	C37-14E	C48	C30
	2850f-2.3E	C37	15E	–	C37-14E	C48	C37
	3000f-2.4E	C37	15E	–	C37-14E	C48	C37
	3150f-2.5E	C37	15E	–	C37-14E	C60	C37
	3300f-2.6E	C37	15E	–	C37-14E	C60	C37
Composite lumber							
Arrowood	—	C24	10E	–	C21-10E	–	–
Lamineer	22f	C30	15E	–	C30-15E	C37	C37
Microlam	2.2E	C37	15E	–	C37-14E	C48	C48
	2.0E	C37	14E	–	C37-14E	C37	C48
	1.8E	C30	12E	–	C30-12E	C37	C37
Paralam	—	C37	14E	–	C37-14E	C48	C48
Gang-lam	4250f-2.4E	C60	15E	–	C37-14E	C60	C60
	3200f-2.2E	C48	15E	–	C37-14E	C60	C60
	3100-1.8E	C37	12E	–	C30-12E	C48	C37

[a]? indicates a stress class level that does not make the primary property stress class level.
[b]Not assigned on species independent basis.
[c]Assignment is based on the characteristic MOR, characteristic density, and mean MOE.

Table 13—A potential stress class system based on bending properties of 2 by 8 lumber at 15 percent moisture content[a]

Class	MOR ($\times 10^3$ lb/in^2)	MOE ($\times 10^6$ lb/in^2)	UTS ($\times 10^3$ lb/in^2)	UCS ($\times 10^3$ lb/in^2)	Specific gravity	C-Perp ($\times 10^3$ lb/in^2)	Shear ($\times 10^3$ lb/in^2)
SC 1	0.4	0.50	0.2	0.6	0.3	0.30	0.22
SC 2	0.9	0.70	0.5	1.3	0.3	0.30	0.22
SC 3	1.4	0.85	0.8	1.8	0.3	0.30	0.22
SC 4	1.7	0.95	1.1	2.0	0.3	0.30	0.22
SC 5	2.2	1.10	1.3	2.4	0.4	0.60	0.28
SC 6	3.0	1.30	1.8	2.7	0.4	0.60	0.28
SC 7	3.5	1.50	2.1	2.9	0.4	0.60	0.28
SC 8	4.4	1.80	2.6	3.0	0.5	0.90	0.36
SC 9	4.9	1.90	2.9	3.1	0.5	0.90	0.36
SC 10	5.5	2.10	3.3	3.2	0.5	0.90	0.36
SC 11	7.0	2.60	4.2	3.6	0.5	0.90	0.36
SC 12	8.7	3.10	5.2	4.4	0.5	0.90	0.36

[a]MOR, UTS, UCS, C-Perp, and shear are 5th percentile values; MOE and specific gravity are mean values. Specific gravity is based on ovendry weight and ovendry volume. More precise estimates of specific gravity, C-Perp, and shear may be made using the specific species specification given in Table 7.

In addition, the assignment of MOE of composite lumber products presents some problems. This is probably because these products have been specifically designed to have a higher MOR value for a given MOE.

We suggest two alternatives for assigning the final stress class level. First, final stress class assignment could be based on only MOR and MOE assignments. Although this procedure might be satisfactory when data are not available on other properties, it would be hard to support when existing data failed to support properties assigned to other test modes. A second alternative would be to assign the stress class based on the minimum stress class determined from any of the individual failure modes. The second alternative has the advantage that it would not result in a higher allowable property being assigned to a specific grade than was already applicable to that grade using existing standards procedures.

Other Considerations

Specific Gravity, C-Perp, and Shear

Specific gravity values vary little with grade and therefore with MOR (Table 15). Thus, the values given in the stress class system presented in Table 13 must be set at a very conservative level. Yet, these properties, especially specific gravity, are often quite important in the design process. Some historical standards use an alternative density class system to alleviate this problem. However, an alternative density class system would reduce the simplicity of the stress class system for initial design estimates. We suggest that the conservative values in Table 13 be used for initial design estimates or for noncritical applications, and the more realistic values in Table 7 be used in the final design when the species to be used in the structure is known.

Lumber Sizes and Moisture Contents

The stress class system presented in Table 13 applies only to dimension lumber for dry use. Adjustment to other lumber sizes and moisture content levels could be handled through tabulated adjustment factors. Alternative options include providing one stress class table for lumber $\leq$6 in. in width and another table for lumber >6 in. in width. For lumber at other moisture content levels, tables with adjusted class boundaries could be provided.

Reliability-Based Design

Improvement in the consistency of the stress class system across product types could be obtained through the use of reliability-based design procedures. Efforts at establishing a reliability-based design code for lumber are nearing completion in Canada and are well underway in the United States. However, many decisions needed to gain acceptance of a stress class system are not dependent upon final decisions on reliability-based design procedures. Assuming that the final reliability-based design process will be of a load and resistance factor format, the resistance factor Rn for a specified target reliability would simply be

Table 14—Stress class assignment for North American lumber using the system in Table 13[a]

Product	Grade	Stress class assignment						
		MOR	MOE	UTS	UCS	Specific gravity	Shear	C-Perp
Visual stress rated								
Douglas Fir–Larch	S.S.	8	8	8	10	8	8	8
Southern Pine		9	8?	8	11	9	9	9
Hem–Fir		7	7	7	8	7	7	7
Canadian Spruce–Pine–Fir		6	6	6	6	6	6	6
Douglas Fir (South)		7	6?	7	10	7	7	7
(Minor) Southern Pine		7	7	7	9	8	8	8
Douglas Fir (North)		7	8	7	11	8	8	8
Hem–Fir (North)		7	7	7	10	7	7	7
Douglas Fir–Larch	No. 2	5	7	5	5	8	8	8
Southern Pine		5	7	5	6	9	9	9
Hem–Fir		5	6	5	5	7	7	7
Canadian Spruce–Pine–Fir		5	6	4	4?	6	6	6
Douglas Fir (South)		5	5	5	5	7	7	7
(Minor) Southern Pine		5	6	5	5	8	8	8
Douglas Fir (North)		5	7	5	7	8	8	8
Hem–Fir (North)		5	7	5	7	7	7	7
Machine stress rated								
	900-1.0E	4	4	2?	2?	–	–	–
	1200-1.2E	5	5	4?	3?	–	–	–
	1350-1.3E	5	6	5	4?	–	–	–
	1450-1.3E	6	6	5?	4?	–	–	–
	1500-1.3E	6	6	6	4?	–	–	–
	1500-1.4E	6	6	6	4?	–	–	–
	1650-1.5E	6	7	7	5?	–	–	–
	1800-1.6E	7	7	7	6?	–	–	–
	1950-1.7E	7	7	8	7	–	–	–
	2100-1.8E	8	8	10	10	–	–	–
	2250-1.6E	8	7?	10	10	–	–	–
	2250-1.9E	8	9	10	10	–	–	–
	2400-2.0E	9	9	10	11	–	–	–
	2550-2.1E	9	10	11	11	–	–	–
	2850-2.3E	10	10	11	11	–	–	–
	3000-2.4E	10	10	11	12	–	–	–
	3150-2.5E	10	10	12	12	–	–	–
	3300-2.6E	10	11	12	12	–	–	–
Composite lumber								
Arrowood	—	7	7	–	–	–	–	–
Lamineer	22f	9	10	10	12	–	–	–
Microlam	2.2E	10	10	11	12	–	–	–
	2.0E	10	9?	10	12	–	–	–
	1.8E	9	8	10	12	–	–	–
Paralam	—	10	9?	11	12	–	–	–
Gang-lam	4250-2.4E	12	10?	12	12	–	–	–
	3200-2.2E	11	10?	12	12	–	–	–
	3100-1.8E	10	8?	11	12	–	–	–

[a]Specific gravity, C-Perp, and shear for MSR lumber may use species specific values for stress class assignment.

[b]? indicates a stress class level that does not make the primary property stress class level.

Table 15—Specific gravity of In-Grade lumber[a]

Species group	Size	Grade	Sample size	Specific gravity	
				Mean	5th percentile mean
Douglas Fir–Larch	2 by 4	Select Structural	818	0.51	0.80
		No. 1	381	0.48	0.83
		No. 2	767	0.49	0.79
		Construction	275	0.48	0.82
		Standard	273	0.48	0.81
		Utility	273	0.47	0.80
		Stud	227	0.49	0.80
	2 by 8	No. 2	971	0.50	0.80
Hem–Fir	2 by 4	Select Structural	828	0.43	0.79
		No. 1	388	0.41	0.80
		No. 2	794	0.42	0.79
		Construction	280	0.41	0.81
		Standard	280	0.42	0.79
		Utility	265	0.41	0.80
Southern Pine	2 by 4	Select Structural	806	0.57	0.79
		No. 1	203	0.52	0.81
		No. 2	820	0.52	0.80
		Stud	179	0.54	0.75
	2 by 8	No. 2	757	0.54	0.78

[a]Green and Evans (1989).

$$Rn = R05 \times Phe$$

where R05 is the 5th percentile strength value, and Phe is a resistance factor for a specific type of strength mode. Thus, stress class boundaries given in Table 13 could easily be adjusted by the assumed Phe values to convert the "deterministic" system into a "reliability" system. Thus, many vital decisions concerning implementation of stress class system could proceed while new reliability-based design codes were being considered.

Quality Control

Engineers involved in lumber design often cite the need for better consistency in product reliability across product types and with products from different sources. This concern usually includes the desire for direct evaluation of claimed properties. Such direct measurement quality control schemes are already in place for MSR lumber and some composite lumber products. Currently, however, no such schemes are used for visually graded lumber. Appropriate quality control procedures for all lumber types would be of significant benefit in assuring engineers of the reliability of lumber carrying a stress class designation. Most engineers would agree that the same reliability would not be required of a low-grade material being used in a repetitive member light-frame application as would be required of a high-grade material being used in highly engineered structures. The point of contention is the level at which more rigorous quality control measures are required.

At a recent technical conference on wood engineering, an informal Delphi survey (Corotis and others 1981) was given to some engineers in attendance. The engineers were asked, At what stress level would you judge that claimed MOR values should be verified using some type of quality control scheme involving proof-loading? The engineers were not told the particular lumber application. From the 15 responses, it appeared that most felt lumber having dry allowable bending strengths greater than 1,500 to 2,000 lb/in^2 (stress class MOR values greater than 3,100 to 4,200 lb/in^2) should be subjected to direct measurement quality control (Table 16).

If it is assumed that a proof-load quality control scheme is viewed as an essential part of a stress class system, will lumber not subjected to proof-loading quality control schemes be excluded from the higher stress classes? It seems that such exclusion would be a restraint of trade and not allowed under the current legal system. Further, such a restriction seems unnecessary for an otherwise high-quality product.

Table 16—Results of informal Delphi survey[a]

Engineer background	Critical MOR[b] (lb/in^2)
Academia	3,780
Government	4,200
Industrial	4,200
Academia	3,360
Consulting	3,150
Consulting	2,100
Industrial	3,465
Academia	3,650
Academia	3,150
Government	3,150
Academia	4,200
Industrial	3,150
Government	3,465
Consulting	3,150
Consulting	3,150

[a]Response of 15 engineers when asked, At what stress level would you judge that claimed MOR values should be verified using some type of quality control scheme involving proof-loading?
[b]Critical MOR is 2.1 × F_b.

One alternative for allowing all lumber into the higher stress classes would be to require confidence in setting the allowable properties of a grade not subjected to quality control. Suggestions have included using a 75-percent tolerance limit to calculate properties if quality control has been used and requiring a 95-percent tolerance limit if no quality control is used. Another alternative would be to allow a three-parameter Weibull distribution to be used to calculate allowable properties when proof-loading is used and to require a two-parameter Weibull when proof-loading is not used. Neither approach, however, appears to consistently produce enough difference in design values to offer real differences in stress class assignment. Perhaps the best alternative is to require a one-class reduction in an assigned stress class level when quality control procedures involving proof-loading are not used. In any case, if the system is to be accepted by practicing engineers and critical user groups, we strongly suggest that an appropriate quality control scheme be required as part of a stress class system for use in the United States.

Recommendations

On the basis of the information presented in this report, we recommend the following:

1. Develop a stress class system for use in the United States.
2. Base MOR and MOE provisions of the system on generally accepted international systems.
3. Apply the system to visually and mechanically graded solid-sawn lumber and to composite lumber products.
4. Establish appropriate provisions in the system for quality control procedures.
5. Locate an appropriate consensus forum for development and implementation of a U.S. stress class system.
6. Base final assignment of grades to stress classes on reliability analysis.

We also note that little, if any, information exists on property ratios for hardwood lumber, and information in the United States is insufficient on the shear–MOR relationships assumed in Eurocode 5. We recommend that these relationships be investigated.

Acknowledgment

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